UNIVERSITY OF GLOUCESTERSHIRE

at Cheltenham and Gloucester

Ingram, Julie (2014) Agricultural adaptation to climate change: new approaches to knowledge and learning. In: Climate change Impact and Adaptation in Agricultural Systems. CAB International, Wallingford, pp. 253-270. ISBN 978-1780642895

Ingram, Julie (2014). Agricultural adaptation to climate change: new approaches to knowledge and learning. In: Climate change Impact and Adaptation in Agricultural Systems. CAB International, Wallingford, UK 253-270.

Chapter 16
Agricultural adaptation to climate change: new approaches to knowledge and learning

In: Fuhrer, J. & Gregory, P. J. (Eds). 2014. Climate change Impact and Adaptation in Agricultural Systems. CABI, Wallingford, pp253-270

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15.1 Introduction

A better understanding of how agricultural adaptation can be supported is needed if practices and systems such as those proposed in the preceding chapters are to be utilized effectively. In particular it is important to understand how the flow of knowledge can be enhanced to support and enable adaptation. It has become clear that complex problems like climate change, and the uncertainty associated with them, require adaptive solutions and a focus on resilience at the farm level. The centrality of knowledge in formulating these solutions is apparent, both with respect to providing technological solutions and valid scientific information and to facilitating farmer learning and strengthening the adaptive capacity of farmers, institutes and communities (IAASTD, 2009).

This chapter focuses on knowledge needs for farm level agricultural adaptation. Although there is a large literature exploring the many dimensions of, and barriers to, climate change adaptation, there has been little analysis of knowledge requirements for agricultural adaptation. This chapter therefore draws on relevant work in areas such as extension and innovation science, and farmer decision making and behavioural research in the wider context of sustainable agriculture and rural development. The term knowledge is used here in its broadest sense incorporating information and advice. However, these represent qualitatively different concepts. Information comprises facts and interpretations, knowledge refers to how people understand and attribute meaning to this information, while advice implies a recommendation based on acquired knowledge.

Agricultural adaptation options are multiple and diverse and this presents challenges for the Agricultural Knowledge System (AKS), the set of agricultural actors, organisations, and their linkages engaged with supporting farmer decision making. A number of approaches to providing farmers with the knowledge and means to adapt and innovate have emerged. These operate against a backdrop of transition in the AKS, with a shift away from pushing the *adoption* of technological solutions towards enabling *adaptation* through facilitation, learning and innovation. This has been in response to a growing recognition that challenges such as adapting to more sustainable and resilient systems require new approaches to engaging farmers. Farmers' utilisation of knowledge is influenced by a number of factors including the quality and perceived relevance and credibility of the information; while their ability to use knowledge depends on institutional contexts and household status. Thus, simply supplying knowledge is not enough to achieve adaptation, wider institutional changes are also required. Amongst these is the need to strengthen the AKS. This chapter therefore focuses on individual adaptations at the farm level but places the discussion within the wider context of agricultural knowledge and innovation systems where potentially planned adaptations can occur.

15.2 Knowledge needs for agricultural adaptation to climate change

15.2.1 Adaptation to climate change - complex knowledge needs

Adaptation is generally described as those responses by individuals, groups and governments to climatic change or other stimuli that are used to reduce their vulnerability to adverse impacts (Bradshaw *et al*., 2004). It refers to changes in processes, practices, and structures in response to the actual or perceived threat of climate change, as well as changes in social and institutional structures and technical options (Howden *et al*., 2007). Adaptive capacity refers to the potential or capability of a system or an individual to make these adjustments. Studies indicate that individual adaptations tend to be incremental and ad hoc, to take multiple forms, to be in response to multiple stimuli, and to be constrained by economic, social, technological, institutional, and political conditions (Smit and Pilifosova, 2001). Consequently knowledge needs for farm level individual adaptations will be complex.

15.2.2 The multiple forms of adaptations have implications for the provision of knowledge

Agricultural adaptation to climate change is a complex, multidimensional, and multi-scale process that takes on a number of forms. A wide variety of agricultural adaptations to climatic variability and change are available (Bryant *et al*., 2000; Smit and Skinner, 2002; Bryan *et al*., 2009). Adaptations in agriculture have been characterized according to a number of attributes such as the form they take (technological or behavioural); purpose (to sustain current activities or to develop new ones); intent (spontaneous or planned); timing (reactive, concurrent or anticipatory); duration (short or long-term); spatial extent (localized or widespread); responsibility (e.g. government, producers, etc.); and to individuals' choice options (Smit and Pilifosova, 2001). At the farm-level possible adaptations to climatic variability and change therefore are multiple and can be implemented at different levels of intensity and duration. Tactical and strategic actions are distinguished. For example, farmers can adapt tactically, or fine tune at a micro scale, to climate change conditions by changing the timing of planting, input use and harvesting (de Loe *et al*., 2001) while they can also adapt strategically by altering soil management practices such as tillage (Dumanski *et al*., 1986) or their selection of crop types/varieties (Mendelsohn, 2000), by diversifying their farm enterprise (Kelly and Adger, 2000), or purchasing crop insurance (Smit, 1994). Such multiple forms of adaptations have implications for the provision of knowledge, tailored, place-specific advice being more appropriate than a 'one size fits all' approach.

15.2.3 Behavioural adaptation is qualitatively different from incremental adjustments

Some commentators refer to actions at managerial level which are short-lived and consistent with existing management practices as adjustments, and to actions which result in a more fundamental change in the system as behavioural adaptation (Bryant *et al*., 2000). The latter goes beyond technological fixes and focuses more on long term change to different kinds of activities and restructuring. These are evident in more dramatic ways such as broad scale shifts in systems, either at the farm system or community scale (Smithers and Smit, 1997). This behavioural adaptation is qualitatively different from incremental adjustments and as such requires different ways of providing knowledge where facilitation, rather than promoting adoption of innovations, is believed to be most appropriate. Farmers, and their supporting institutions, also need to change established frames of reference for thinking and acting. Pelling (2010) highlights the role of social learning in enabling such transformational adaptation which builds on alternative values and norms.

15.2.4 Adaptations are hard to identify

Farmers are continuously adapting to a number of stresses and changes and their adaptation actions in response to climatic events often revolve around the complex interplay of other non-climate factors such as market forces (cost/ price ratios, consumer demands, etc.), institutional factors etc. As such, adaptation actions tend to constitute 'on-going processes, reflecting many factors or stresses, rather than discrete measures to address climate change specifically' (IPCC, 2007, p.720). Thus, not only are there multiple adaptation options available to farmers but also diverse and unpredictable adaptation responses. Because of this there is some debate as to whether suitable adaptive strategies are actually discernible. Whilst adaptations that are generally suitable for managing climate-related risks can be identified, some argue that it is not so easy to identify adaptations that are suitable for managing multiple risks such as downturns in commodity markets, changes to government policy and support (Dolan *et al*., 2001; Bradshaw *et al*., 2004). In this sense adaptations are hard to 'pin down', and prescribe; formulating the right sort of knowledge to support them is equally difficult.

15.2.5 Adaptation not adoption

Although a variety of technological innovations have emerged from science to assist farmers in managing climate change, simply supplying interventions does not provide the certainty of successful adaptation; ultimately this rests on the adoption and successful implementation of specific strategies. Considerable effort has been spent on examining the constraints to, and opportunities for, adoption of innovations, although this 'supply-led' focus is only one approach. Adaptation is a process and, rather than relying on farmers to adopt 'bolt-on' technologies, there should be more emphasis on the adaptation of principles to place. As with other adaptive processes or systemic changes in farming, such as a shift from conventional to agro-ecological/organic farming or from plough to conservation tillage systems, there is no blue print. Evidence from studies of other agricultural transitions has shown that locally adapted solutions are knowledge intensive, complex and non-prescriptive, requiring incremental learning, as well as a good understanding of the local agro-ecosystem (Kroma, 2005). Supporting learning, rather than teaching, should therefore, it is argued, underpin approaches supporting adaptation.

15.2.6 Maximising production is often no longer the main goal

Increasing the resilience of the system to cope with change is one of the cornerstones of climate change adaptation. Resilience is defined by the IPCC (2007) as the ability of a social or ecological system to absorb disturbances while retaining the same basic structure and ways of functioning, the capacity for self-organization, and the ability to adapt to stress and change. The context in which farmers manage their farms is continually in a state of flux in response to changing circumstances. Climate change, increasing frequency of extreme climatic events, and the long term prospect of climate variability, is a key source of uncertainty; however, it is not the only one, with the biophysical environment, markets, resources and supplies also changing unpredictably. Given such turbulence and uncertainty farmers are seeking resilient farming systems that can be sustained despite large fluctuation in yields, prices, diseases, climate etc. (Darnhofer *et al*., 2010). As a consequence maximising production is often no longer the main goal, and this has implications for knowledge provision.

15.2.7 Communicating risk is a key feature of climate change adaptation

Communicating information about climate variability and extremes and the associated risks requires a particular approach and specific types of and information. The focus needs to shift from formulating options and knowledge for average conditions to supporting learning for uncertainty and variability. As such, rather than promoting field crops whose spatial range has been extended for average climatic conditions there is a need now to promote broadly adapted species that are tolerant of inter-annual variations. This distinction is important, for it is these deviations from so-called normal conditions that may well define the experience of climate change (Smit *et al*., 1999). Also given the context of multiple risks (e.g. market fluctuations), some argue that there is need to consider all of the key sources of risk to provide effective decision making and learning for farmers and thus improve decision makers' 'climate knowledge' overall (Meinke *et al*., 2006).

Thus agricultural adaptation to climate change is a complex process leading to multiple adaptation options and choices, from minor adjustments to fundamental shifts in farm systems and farmer behaviour. It is an on-going process reflecting many factors or stresses, where risk is a central element and resilience is often the goal. Farmers operating in this challenging arena need the appropriate knowledge and support if they are to develop effective adaptation solutions. A discussion of these needs can be framed within the debates concerning the transition of the Agricultural Knowledge System (AKS). This provides a useful framework in which to understand the communication activities of many actors and institutions operating in agriculture.

15.3 Agricultural Knowledge Systems and adaptation to climate change

15.3.1 Agricultural Knowledge System in transition

In line with the emerging challenges and transformations in agriculture associated with large scale threats such as food security, water insecurity and resource degradation, and the new ecosystem services required from agriculture, there has been an evolution of ideas about knowledge and innovation (EU SCAR, 2012). The original AKS, understood as the 'triangle' of agricultural research, education and extension (advisory service) establishments (Rivera and Sulaiman, 2009), has made great contributions to the development of food provision and rural development. However, the need for transition in the AKS to make it fit for purpose in a new agricultural context has been widely articulated (Knickel *et al*., 2009). Earlier linear models of knowledge transfer from science to practice failed to represent the increasingly pluralistic and fragmented arrangements of actors, institutions, structures and multiple sources of knowledge. Instead the notion of AKS evolved to describe a complex set of agricultural organisations and/or persons, and the links, networks and interactions between them, engaged in all knowledge processes with the purpose of supporting decision making and innovation in agriculture (Röling and Engel, 1991). In AKS theory the debate has moved on from a concentration on the interaction between farmers and technologies/science to incorporate wider perspectives of institutional change and innovation systems perspectives (Hall *et al*., 2006). These theoretical developments in the AKS frame our understanding of the flows of knowledge between actors and institutions and of the approaches used to provide farmers with information, knowledge and advice.

In the agricultural extension literature it is possible to document an evolution in theory and practice from persuasive 'knowledge transfer' approaches to more facilitative 'human development' perspectives (Roling and Jiggins, 1994). Theory and methodology has traditionally been predicated on the promotion of technological innovations with a reliance on the top-down, uni-linear model of transfer from science to practice (the knowledge transfer model). This notion of a 'one-way' path was developed and adapted by a number of authors, the most pervasive being Roger's diffusion of innovation theory (Rogers, 1995) and the technology transfer (TOT) model which has underpinned the activities of many extension services and development activities.

However, this supply-driven paradigm has been criticised for reflecting what interventions are available rather than the needs of farmers in their local context, and specifically for failing to equip them with appropriate knowledge to meet the multiple challenges they are facing (Roling and Jiggins, 1994). Assumptions that farmers are a homogenous group and as such respond uniformly to one-size fits all technologies; that non-adopting farmers are 'dumb', that they just need the 'right' information or technology to respond; and that farmers do not contribute any knowledge of their own to the process have been shown to be flawed. In response to these criticisms a range of 'human development' approaches emerged incorporating the principles of participation and facilitation of farmer learning drawing on their experiences and knowledge. Here the implication is that, given the right conditions, information, mutual interaction and opportunity, land managers will use their own knowledge and develop their own appropriate solutions to their problems. However, as Black (2000) points out, belief in a 'participation fix' may be as naïve as in a 'technological fix'. Thus while commentators often conceptualise the top-down technology transfer based on scientific knowledge and the bottom-up participatory approaches drawing on local knowledge as two ends of a spectrum, the territory in-between is of most interest.

15.3.2 Climate change adaptation and Agricultural Knowledge Systems

In agriculture, among the most frequently advocated strategies for climate adaptation is technology research and development. The development of technologies to assist farmers in managing the vagaries of weather has been an important focus of agricultural research over the past several decades and many examples exist of previous technological innovations that have provided farmers with the means to respond to climatic limits and possibilities, both with respect to new crop varieties and better agronomic practices (see Chhetri *et al*., 2012 for a review). For example, developing technological capability to help improve the efficiency and resilience of the agriculture sector to enable it to respond to climate change is recommended as a future strategy in the UK (Committee on Climate Change, 2013). As such there is an abiding belief in the ability of technology to continue to provide farmers with the needed strategic and tactical options for handling future weather-related uncertainties, although the alternative view that questions whether climate innovations in agriculture will flow when needed has been voiced with reference to a number of institutional and economic constraints (Smithers and Blay-Palmer, 2001).
Beyond the issue of technological innovation there are further critiques of this technology-centred discourse, mainly with respect to assumptions concerning on-the-ground adaptation through agricultural extension and farmer adoption of specified strategies. The supply-led approach assumes that to achieve effective responses to climate the 'problem' lay not so much in the ability to develop innovative solutions, but in the farmers' ability to adopt them, and therefore the challenge of developing effective strategies for adaptation lies with technology transfer, that is, persuading farmers to adopt (Smithers and Blay-Palmer, 2001). The acceptance and implementation of new practices at the farm level is a fundamental element of technology-related climate adaptation in agriculture and there has been extensive behavioural research looking at socio-economic determinants that influence farmer decision making and the probability of uptake of adaptation measures (e.g. Bryan *et al*., 2009). These have explored, for example, farmer perceptions of risk and related farm management decisions, including those related to the use of selected technologies (Brklacich *et al*., 1997). However, whilst this research has provided insights into the process of innovation adoption, there has been less emphasis on the role of farmer knowledge in 'adapting' technologies to local conditions and on their experience of managing past climatic risks (Christoplos, 2010). Significantly, this approach fails to fully address the complex knowledge needs of adaptation which, as noted earlier, requires the adaptation of principles to place and learning rather than the adoption of technological fixes (Darnhofer *et al*., 2010). It is argued that adaptation in increasingly complex situations requires that the emphasis be placed on empowering individuals and groups to engage in ongoing learning. In particular, a context of uncertainty and unpredictability requires continuous learning processes that

incorporate new information and experiences and individual experimentation (Funtowicz and Ravetz, 1993; Folke *et al*., 2003).

As reflected in the theoretical discussion of knowledge transfer, the middle ground between these two extremes, technological innovation and farmer learning, is arguably most suited to formulating approaches to supporting farm level adaptation. Whilst learning and drawing on local knowledge are important, new complex environmental problems need innovation, scientific input and technical know-how. It is considered that it is unfair to expect farmer groups to solve difficult and complex problems alone and that often farmers' knowledge and their ability to learn and cope unsupported are over-romanticised; this is particularly the case when considering the inherent risks associated with climate variability and extremes. Also importantly, farmers have individual learning styles, they learn about innovations in different ways and therefore need different levels of engagement. A combination of scientific and the human development solutions therefore can be regarded as an effective model, and in practice a mix of approaches to providing knowledge for climate change adaptation are likely to be employed.

Furthermore there has been increasing recognition that technological innovations in agriculture come from multiple sources including public institutions, private firms, and farmers. Countries that have been successful in developing location-specific technologies have been able to "socialize" the process of technological innovation, that is, to increase interactions between farmers and their supporting institutions (Hayami and Ruttan, 1985). As such innovation of technologies at the local level is crucial for enhancing adaptive capacity of farmers. This draws on, both local knowledge from farmers operating under specific climatic conditions, and on scientific knowledge embedded in the institutions that are designed to minimize uncertainties at the decision level (Chhetri *et al*., 2012).

15.4 Approaches to providing knowledge for agricultural adaptation to climate change

Many options for policy-based adaptation to climate change have been identified for agriculture (Agrawal, 2008). Actions associated with building adaptive capacity including financial incentives, developing infrastructure and capacity building in the broader user community and institutions have been proposed by a number of commentators (see Adger 2003, for example). With respect to knowledge, government activities typically comprise communicating climate change information, specifically improving the state of weather forecasting and building awareness of future scenarios and potential impacts; and providing information about farm-level adaptations. Extension systems have always been a key component of the AKS and public extension (rural advisory) services have a central role in delivering policy measures. These services are critical to dealing with national food security, providing objective information, reaching disadvantaged groups and enabling farmers to deal better with risk. However, although public extension services are important, in an increasingly pluralistic and demand-driven AKS, farmer organisations, NGOs, commercial companies and public-private partnerships are also involved in providing information and support to farmers and as such will have a role in supporting climate change adaptation

A suite of strategies and mechanisms operating within the AKS have developed at a number of scales and governance levels (local, regional, national and international) to provide farmers with the information, the tools and the means to make both short-term adjustments and longer-term more systemic change adaptations to climate change. The nature and extent of these will reflect the varying agricultural contexts and needs of the farmers, the perceived level of vulnerability and adaptive capacity, as well as the market opportunities, institutional resource settings, policy objectives, and state and function of extension services. These approaches will be aligned to, and often integrated with, approaches used to address other large scale issues such as food security, sustainable agriculture, a range of rural development goals which share many of the same knowledge needs as adaptation. However, climate change knowledge and advice will need to specifically take into account the risks associated with climate variability and extremes which affect vulnerable farmers (Christoplos, 2010). The following sub-sections describe some of the approaches.

15.4.1 Providing climate information

Communicating information about climate change to raise awareness is a key area of activity for national agencies. This is done using a range of media. Newspapers and radio have been extensively used to reach rural communities in developing countries, with digital technologies increasingly being harnessed as more people gain access to them. Community radio has played an important role in disseminating climate change information (Myers, 2008). For example, in Malawi, where 90% of households are engaged in agriculture, community radio is being used as a catalyst in communicating food security issues caused by climate change.

Improving the state of weather forecasting is a central part of many national adaptation strategies (Bradshaw *et al*., 2004). This involves the provision of information about climate variability and change to help reduce unpredictability associated with climate-events and trends. The Kenya Meteorological Department, for example, releases seasonal forecasts on local radio with a view to helping farmers' cropping decisions. The use of web based tools and initiatives are widespread, with investment in forecasting and early warning capacity increasing in a number of African countries (see www.AfricaAdapt.net).

However, to achieve its potential, rural climate change information needs to be accurate, accessible to, and useful for farmers. The usefulness of climate information has been shown to be a key determinant of adaptation (Roncoli *et al*., 2002; Deressa, *et al*., 2009). The quality of the climate forecasts is important. Accurate climate forecasts have been found to improve household well-being while poor forecast information has been shown to actually be harmful to poor farmers (Ziervogel *et al*. 2005). Farmers' responses to forecasts also depend largely on their own experiences and observations. Under conditions of climate risk and uncertainty farmer decisions can be based as much on personal experience (e.g. of extreme events; rainfall frequency, timing, and intensity; and early or late frosts) as on forecast information, often giving greater weight to recent events (Vogel and O'Brien, 2006).

Projections of climate change over a range of timeframes from short-term tactical to long-term strategic are also available to help inform farmers (as well as agribusiness, and policy makers) about the implications of a changing climate. However, it is considered important to align the scales (spatial, temporal, and sectoral) and reliability of the information with the scale and nature of the decision. Long-term projections of climate may not be that helpful for farm level decision making, given the high uncertainties at the finer spatial and temporal scales (Howden *et al*., 2007; Newsham *et al*., 2011).

Partial understanding of climate impacts and uncertainty about benefits of adaptation has been identified as a barrier to adaptation (Hammill and Tanner, 2011). Climate change information is often difficult to communicate beyond the scientific community, due to its inherent uncertainty and complexity, so that providing end users with information in a format that is appropriate to them is a challenge. The importance of creating a dialogue between those producing and those using information, often through a brokerage organisation, has been highlighted. For example, in southern Africa a brokerage exercise helped to reveal that scientists' concern with improving the confidence in predicting the start of the rainy season did not match the farmers' interest which was on distribution throughout the season (Davis, 2012). The role of extension is important. Although extension services have always helped farmers adapt to changing climatic conditions using, for example, study circles for farmers to 'talk about the weather', these discussions now need to be scaled up and better informed through increased attention to uncertainty and vulnerability. At the same time more effective ways of 'downscaling' climate forecasts to make them relevant to specific agro-meteorological zones is needed (Christoplos, 2010).

Farmers also need to be convinced that projected climate changes are real and are likely to continue before they make any adaptive changes. In the same way farmers also need to be confident that the projected changes will significantly impact their enterprise. Credibility of information is therefore important. This is backed up from studies in other contexts that have found that credibility, trust in the source and in the messenger is critical if it is to influence behavioural change (Hallam *et al*., 2012; Sutherland *et al*., 2013).

15.4.2 Promotion of climate change agricultural adaptation options

Providing information and advice about different adaptation options is central to government agricultural adaptation strategies (Brklacich *et al*., 2000; Smithers and Blay-Palmer, 2001). Whilst governments acknowledge the value of human development approaches and locally derived adaptive solutions they still need to draw on traditional extension models to achieve policy objectives. A large body of research has grown within the adoption-diffusion paradigm showing the significance of information and examining the relative merits of different communication approaches (see Feder and Umali, 1993). More recent studies such as Maddison (2007) have looked at the relevance of this to climate change adaptation in Africa. Extensive research also provides insights into the determinants of farmer adaptation behaviours, as discussed later.

In the case of climate change, extension services provide information about different adaptation options and resources that might be available to help local actors adapt. Indeed these services have been shown to be a key factor in determining farmers' decisions, facilitating adaptation and enhancing adaptive capacity both by increasing the likelihood of perceiving climate change and in encouraging a response to such a perception (Maddison, 2007; Nhemachena and Hassan, 2007; Bryan *et al*., 2009). However, the demands of adaptation, where the portfolio of adaptation strategies and options is so extensive, present new challenges for extension. Also with rapid and unpredictable changes in local climates and in other factors such as markets, a new paradigm has been called for in extension that rejects blanket advice and favours tailoring advice and adaptation options to specific farmers in specific circumstances (GFRAS, 2012). It is considered that the *modus operandi* of many extension providers needs to change accordingly. Instead of supplying farmers with information and standard protocols about production based on average conditions, extension needs to provide a menu of options and relate this to information about seasonal weather forecasts and probabilities. According to Christoplos (2010) production maximization strategies based on producing a single variety which is expected to perform well in average weather conditions can bankrupt smallholders where increasing climate variability means that average years occur less frequently. This is a new and complex area of work for extension, where the emphasis needs to be more on resilience and less on achieving high production. Instead of encouraging farmers to specialise their production methods and adopt high yielding varieties to be able to enter commercial markets, extension needs to provide advice on the different climate and market risks, this might entail retaining traditional production diversification strategies (agro-biodiversity) that might previously have been dismissed as irrational 'risk aversion' by extension agents. In particular information about expected weather patterns needs to be combined with advice about what crops and varieties are appropriate in new and uncertain conditions. In addition the need for extension agents to change their approaches from teaching to promotion of learning with respect to climate change has been recognised (Christoplos, 2010).

15.4.3 Facilitating farmer collaboration, learning and adaptation

Participatory engagement and collective learning

Much recent climate action has concentrated on building local resilience through participatory techniques and community empowerment. As climate change affects most harshly the poorest populations and social groups, special attention has been directed to local structural inequalities, and the voice and representation in decision-making of these groups (Rodima-Taylor *et al*., 2012). In the context of farming, collaboration and participatory engagement approaches in climate change adaptation allow farmers' needs to be articulated, their practical knowledge to be considered, and the values that are important to them to be recognised. Multi-level institutional partnerships have enabled the efficient transfer of agricultural technologies to farmers. Examining technological innovation in the context of agricultural adaptation to climate change in Nepal, Chhetri *et a*l., (2012), for example, found that collaboration with farmers and NGOs was effective as farmers were taken seriously, not only as end-users, but also as active participants in the innovation of new technologies and this led to more robust and enduring adaptation .

Participatory and collaborative approaches draw on substantial scientific knowledge of agricultural systems but also enable the identification of a range of adaptations that scientists might themselves not explore. Involving farmers allows the assessment of the practicality, cost effectiveness and acceptability of the options. The approach also enables solutions to be formulated that are sensitive to the complexity and variability of farmers' local production environments. Participatory approaches are also useful for developing step-wise mitigation and adaptation strategies against climate change through systematic iterative assessment of the biophysical and the socio economic aspects. Participatory research into climate change adaptation options can help agricultural decision makers realise that acting on the existing trends in climate now is likely to be to their advantage, as research assessing frost free days in Australia has shown (Howden *et al*., 2003). The facilitation of collective or group learning has been applied in many contexts, from longstanding FAO Farmer-Field Schools, to group farmer learning and knowledge sharing in dealing with natural resource management, exemplified by the Landcare approach in Australia. Farm monitoring discussion groups can also provide a collective learning environment. For example, in Scotland's Farming for a Better Climate programme, farmers and experts jointly formulate and assess mitigation options on Climate Change Focus Farms.

Tapping into farmer to farmer learning

The significance of communication within farmers' social networks, where individual members share and influence each other in a context of mutual trust and strong social capital, has been reported for a number of situations (Maddison, 2007). Often variations in environmental perceptions and behaviour can be explained more by the character of social networks, interconnectedness and rule sharing than by demographic variables such as age and gender. Indeed social networks, rather than the form and volume of information, have been identified as a key variable explaining whether people pay attention to climate change and enter into adaptive behavioural change (Rayner and Malone, 1998). It is suggested that networks that have already demonstrated an ability to adapt proactively to challenges might have the inherent capacity for further adaptation like climate change (Pelling *et al.,* 2008). Studies have also highlighted the importance of social networks, social capital and relationships in facilitating or hindering adaptation in the wider community (Adger, 2003; Pelling and High, 2005; Agrawal, 2008). The need for extension efforts to target existing networks or groups with respect to messages about climate change has been recognised (Hallam *et al*., 2012). Another way in which farmers learn about what adaptations are appropriate is from observing and copying their neighbours. Maddison's (2007) review of perception of, and adaptation to, climate change across 11 African countries suggests that strong neighbourhood or clustering effects of adoption of certain technologies, on the basis of what they observe their neighbours doing, leads farmers to update their own prior beliefs.

Facilitating individual learning

Individual experiential learning has always been seen as an essential part of farmer innovation. This style of learning is considered particularly relevant to adaptation where uncertainty requires a continuous learning process that incorporates new information and experiences (Funtowicz and Ravetz, 1993; Berkes, 2009). This is the central tenet of the adaptive approach which emphasises the dynamic nature of the farming context. It considers that with societal and farm dynamics being uncertain, adaptability, resilience and flexibility become as important as maximising production and income (Darnhofer *et al*., 2010). Learning also entails developing so-called adaptive competencies such as critical thinking, problem solving, futures thinking and hindsight, identification and control of variables affecting crops, openness to novelty and collaboration, as described by Pruneau *et al*. (2012) in a study of Canadian farmers' responses to climate change. Extension services can facilitate such learning though encouragement, providing a supportive environment and scientific input and verification where required.

15.4.4 Incorporating local experiences and knowledge

There is growing recognition that efforts to strengthen resilience of farming systems needs to understand and build on local coping strategies (Eriksen *et al*., 2005). Studies have emphasised the hardy adaptive capacity that farmers display in responses to climate and other stresses, and their sophisticated strategies for coping with stress (Newsham and Thomas, 2011). These strategies include: diversified use of the landscape; mobility and access to multiple resources which increase the capacity to respond to environmental variability and change including climate change; maintaining genetic and species diversity in fields and herds to provide a low-risk buffer in uncertain weather environments; and agricultural practices evolved in traditional farming systems (Chhetri *et al*., 2012; Nakashima *et al*., 2012). These experiences of handling climatic challenges in the past provide insights for current and future agricultural adaptation challenges.

Scholars claim that this resourcefulness and resilience demonstrated in the face of climate stresses is rooted in indigenous knowledge or traditional ecological knowledge. The value of such knowledge in dealing with climate change has been increasingly explored (see Nakashima *et al*., 2012 for a review). This recognition has led to the acknowledgement of indigenous knowledge in the Fourth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change (IPCC) as 'an invaluable basis for developing adaptation and natural resource management strategies in response to environmental and other forms of change' (Parry *et al*., 2007; IPCC, 2007). This has been reaffirmed at the 32nd Session of the IPCC which stated that 'indigenous or traditional knowledge may prove useful for understanding the potential of certain adaptation strategies that are cost-effective, participatory and sustainable' (IPCC, 2010).

The role of local knowledge(s) and capacities has long been a focus within development, 'farmer first' approaches to agricultural development, livelihoods and participation (Scoones and Thompson, 1994). Critics, however, point to the risks of mythologising local knowledge and, where local farming practices are implicated in degradation, argue that attributing such knowledge to farmers is misguided. Whilst there is agreement that human systems have evolved a wide range of strategies to cope with climatic risks and that these strategies have potential applications to climate change vulnerabilities, for most systems and communities changes in the mean condition commonly fall within the so called 'coping range'. Many systems, however, are particularly vulnerable to changes in the frequency and magnitude of extreme events or conditions outside this coping range. Furthermore some point to substantial losses from climatic variations and extremes which, they argue, indicates that autonomous adaptation has not been sufficient to offset damages associated with temporal variations in climatic conditions (Smit and Pilifosova, 2001).

The debates about the relative merits of scientific and local knowledge with respect to supporting sustainable agriculture have been long running. There is now an acceptance that, where adaptation and resilience are the goal, agriculture needs to be supported by diverse knowledge systems that enable the co-production of different knowledges. Knowledge co-production is defined as 'the collaborative process of bringing a plurality of knowledge sources and types together to address a defined problem and build an integrated or systems-oriented understanding of that problem' (Armitage *et al*., 2011, p996). Giving validity to both scientific and local knowledge is thought more likely to lead to adaptive forms of environmental management and longer lasting, more effective outcomes than relying only on one source of knowledge. Thus, while traditional knowledge, innovations and adaptation practices are seen to embody local adaptive management to the changing environment, it is the way in which they can complement scientific research, observations and monitoring that is of increasing interest (IIPFCC, 2009).

A number of examples exist of effective knowledge co-production. Indigenous observations and interpretations of meteorological phenomena can contribute to climate science by offering observations and interpretations at a much finer spatial scale and temporal depth than by climate scientists (Nakashima *et al*., 2012). In Africa, rainmakers in the Nganyi community of western Kenya (Guthiga and Newsham, 2011), and farmers in Nessa Village in southern Malawi (Kalanda-Joshua *et al*., 2011), have collaborated with meteorological scientists to produce integrated forecasts that are being disseminated by both indigenous and conventional methods to enhance community resilience. These are seen to be more intelligible, robust and locally useful seasonal forecasts, easier to understand and more relevant to the village level. Although, as Newsham *et al*., (2011) point out, there can be considerable cultural barriers to achieving such collaborations. In another case in North central Namibia, Ovambo farmers were found to have a sophisticated understanding of agro-ecological dynamics which enabled the farming to be resilient to current climatic variability and impacts but not necessarily to future climate change impacts. Incorporating specific features of agricultural science such as the use of early maturing varieties of pearl millet, instead of traditional varieties, and fitting them in to existing patterns of land use was found to be an effective way of increasing adaptive capacity (Newsham and Thomas, 2009).

Failure to engage with local farmers and incorporate their knowledge can mean that extension efforts have limited success (Nakashima *et al*., 2012).

15.5 Adaptive capacity - farmers' ability to engage with knowledge

15.5.1 Enabling access to knowledge

Successful adaptation to climate change by farmers is not merely a question of providing climate information, promoting new adaptation technologies and facilitating learning; it depends on enabling access to these. Individual adaptation actions are constrained and enabled by a number of local and contextual determinants. Considerable attention has been devoted to the so-called determinants of adaptive capacity, which are characteristics of communities, countries, and regions that influence their propensity or ability to adapt and hence their vulnerability to risks associated with climate change. The capacity to adapt to variability and change is seen to be dependent on underlying structures of vulnerability such as levels of poverty, property rights, entitlements to assets (Pelling and High 2005); policy, institutional environment and regulatory structures (Agrawal, 2008); access to technology (Prno *et al*., 2011); availability of human and financial capital; the socio-economic position of the household (Ziervogel *et al*., 2006; Adger *et al*., 2005; Prno *et al*., 2011); access to agricultural services such as extension services and credit, electricity and markets and, tenure status (Nhemachena and Hassan, 2007; Maddison, 2007; Bryan et al., 2009); and weak market systems (Kabubo-Mariara 2009). Put simply for individuals, their capacity to adapt to climate change, and their ability to engage with knowledge and information, "is a function of their access to resources" (Adger 2003, p. 29).

With respect to accessing knowledge for adaptation, studies have shown that access, and the ability to respond to climate forecasts and the benefits obtained from their use are determined by a number of factors including the policy and institutional environment and the socio-economic position of the household (Ziervogel *et al*., 2005; Vogel and O'Brien, 2006). Maddison's (2007) survey of 11 African countries also found that small scale farmers' accessibility to agricultural innovations is often limited by socio-economic institutional deficiencies such as lack of credit or savings, land tenure issues and proximity to the market. In a household survey in Ethiopia and South Africa Bryan *et al.* (2009) found that extension services, information on climate change and government aid facilitated adaptation among the poorest farmers, while wealthier farmers were more likely to adapt given access to land, credit and information about climate change. These studies show that information awareness raising and advice alone is insufficient. For the poorest farmers they also require resources to implement adaptation options (Vogel and O'Brien, 2006). Although the provision of free extension advice may play a role in promoting adaptation particularly with poor households, there are always some costs associated with acquiring knowledge, and as such it is argued that larger farms will most likely be the first to utilise knowledge and adapt to climate change (Maddison, 2007). This suggests that strengthening extension alone is insufficient to ensure adaptation. Complementary activities are also required to enhance the institutional environment, particularly in the case of poorer farmers.

15.5.2 Capacity building –extension services

There is a recognised need for mobilisation of agricultural extension services to achieve a range of food security and rural development goals and part of this is to enable farmers to understand, mitigate and adapt to new climate change challenges (Ozor and Nnaji, 2011; GFRAS, 2012). Policy-makers have been urged to extend and improve adaptation extension services, ensuring that they reach small-scale subsistence farmers. However, few agricultural extension service providers can meet these challenges as capacities are limited in terms of human resources, effectiveness of organisations, funding and, most importantly, leadership and direction (GFRAS, 2012). Extension not only needs to provide information but also to synchronise and make accessible the materials, credit, training and information (at the right place, time and format) needed to ensure that innovations and adaptations are accessible and transaction costs minimized. Long-term institutional development is seen as key. New ways of accessing information (the internet and mobile phones) about the weather, technological options, markets etc. need to be anchored in a stable and coherent institutionalized extension infrastructure if they are to be effective. Whilst a weather forecast may be helpful, it may only be useful if the farmer can discuss the implications of that forecast with respect to what to plant, and how to access markets for any new varieties (Christopolos, 2010; GFRAS, 2012). The need to build capacity in delivering information and advice is not restricted to developing countries. Developed country governments have been called upon to renew their focus on disseminating climate change advice, research and technologies to farmers (Committee on Climate Change, 2013).

15.6 Understanding farmers' adaptation responses

As well as understanding farmers' ability to adapt in terms of accessing resources, considerable attention has also been devoted to the personal determinants of farmer adaptive capacity. Studies of farm-level adaptation using household datasets have shown that the probability of uptake of adaptation measures to climate change is influenced by a range of personal socio-economic attributes including: farmer education, age, farming experience and perceptions and awareness, and willingness, as well as farm factors such as size, farm assets and wealth factors (Smit *et al*., 1996; Brklacich *et al*., 1997; Bryant *et al*., 2000; Bradshaw *et al*., 2004; Maddison, 2007; Nhemachena and Hassan, 2007**;** Bryan *et al*., 2009; Below *et al*., 2012). This research, in aiming to predict farmer responses to prescribed adaptations and innovations, implicitly assumes a role for supply-led research.

Perception of climate change is one factor that increases the probability of adaptation (Bryant *et al*., 2000). However, a number of studies describe the disconnect between farmers' perceptions of climate change and actual adaptation (Smit *et al*., 1996). In Canada, for example, Brklacich *et al*. (1997) found that farmers, despite having perceived climate changes, did not adapt their farming practices. This was attributed to declining relative importance of climate in relation to other factors influencing farm-level decision-making as well as built in resilience of the agriculture system. Similarly Bryan *et al*'s (2009) study of adaptation decisions based on household surveys conducted in Ethiopia and South Africa found that, despite having perceived changes in temperature and rainfall, a large share of farmers in both countries did not take any adaptive measures. Maddison (2007) from a study of 11 African countries found that, whereas farming experience determines whether or not farmers perceive climate change, farmer education largely determines whether or not they adapt to it. These examples reveal the difficulty in understanding farmers' adaptive responses due to the influence of a number of competing factors. In other research, using data from over 15,000 Canadian prairie farms Bradshaw *et al*. (2004) found that, rather than diversify their crops, an adaptation strategy which would reduce risks from climate change and variability, farmers in the region were actually becoming more specialized due to economic considerations, such as the high start-up costs and implications for achieving economies of scale.

The heterogeneity of human decision-making and behaviour makes it hard to predict farmer responses to climate stimuli. In a study of Canadian farmers, Bryant *et al*. (2000) showed that different agricultural systems and market systems in which farmers operate and their different individual characteristics and contexts such as personal managerial style and entrepreneurial capacity and family circumstances influence farmers' responses to climatic stimuli. As such, they are found to respond differently when faced with the same climate stimuli, even within the same geographic area. This accords with studies of farmer behaviour in other contexts where researchers have demonstrated the influence of different motivations, cultural norms, habits, identity, farming styles, values, goals and worldviews on farmers' environmental behaviour (Siebert *et al*., 2006). With respect to climate change adaptation this was demonstrated in a study that found poor farmers are likely to take measures to ensure their survival while wealthier farmers make decisions to maximise profits (Ziervogel *et al*., 2006). According to Rayner and Malone (1998) farmers rarely choose the best responses to climate change, that is, those that would most effectively reduce losses, often because of an established preference for, or aversion to, certain options. Given this heterogeneity and inherent variability in individual behaviour, the assumption that all farmers behave as rational economic decision makers has been shown to be untenable. This has implications for government extension programmes. It also leads some to question the widespread belief that adaptation strategies can generally be recognised by analysts and extension officers (Dolan *et al*., 2001).

15.7 Conclusion

Effective and resilient adaptation solutions to climate change require new approaches to knowledge and learning. A combination of scientific and human development solutions is considered most appropriate drawing on the provision of climate information (communicating risk, weather forecasting etc), promotion of adaptation technologies, facilitation of farmer learning and the co-production of knowledge. In practice the approaches used will be a function of intensity of the stress, the perceived level of vulnerability and adaptive capacity of the farmer, scale of activity, government resources, policy objectives, and nature and capacity of the AKS.

The ability of governments and other bodies to implement communication approaches effectively depends largely on the capacity of the AKS. Strengthening the AKS to meet the challenges of adaptation to climate change can be directed to a number of areas including improving the quality, credibility and usefulness of information (Howden *et al*., 2007; Deressa et al., 2009). Extension services are a central component of the AKS that need to be enhanced. Here the challenge is, not only communicating climate risk, providing a portfolio adaptation options and supporting learning, but also ensuring that farmers can utilise this by providing support with respect to accessing markets, credit etc. Another area for attention is addressing the science-action knowledge gap to achieve a more integrated AKS for climate change adaptation, both by enabling effective communication about climatic variability and risk between science and practice (Kristjanson *et al*., 2009) and by investing in applied research. The disconnection between climate science and policy which has led to a lack of use-inspired research has also been identified as barrier to adaptation, as has the lack of adequate channels to enable farmer feedback into the innovation process.

Communication and engagement processes between individuals and institutions are an important consideration in the institutional and structural barriers to climate change adaptation and involvement of different actors provides the basis for sharing of different forms of knowledge (Raymond and Robinson, 2013). Boundary organisations and extension services are seen to pay key brokerage role in this respect (Christoplos, 2010). In the face of climate change risks and impacts that remain uncertain and unpredictable, the need for policies and action that foster such collaboration and co-production of knowledge, as well as the building of partnerships and alliances between farmers and their supporting institutions, is widely articulated (Newsham and Thomas, 2011; Chhetri *et al*., 2012).

A critical area of AKS development is the need to provide an enabling environment and strengthening the capacity of different actors, both to create, diffuse and use knowledge but also to access resources and services. In recognition of the wider institutional, political and commercial contexts in which farmers operate the theoretical notion of AKS has evolved to Agricultural Innovation Systems (AIS) or Agricultural Knowledge and Innovation Systems (AKIS) (Hall *et al*., 2003; EU SCAR 2012). In line with these wider perspectives of the role of knowledge there is a need to recognise that, as well as responding to climatic events, farmers are also continuously adapting to fluctuations in markets, policy etc. Thus to provide effective decision making and learning for farmers the AKS needs to consider all of the key sources of risk (Meinke *et al*., 2006). By making agricultural adaptation measures and approaches consistent, or integrated, with other approaches and programmes that address non-climatic stresses and risks there is greater chance of effectiveness. As the goals underlying adaptive capacity are closely connected to wider agricultural and rural development issues, opportunities for achieving this alignment are present.

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